(The following files OCR'd by Charles R. Patton from a printout on 10/24/2005 from:
http://home.earthlink.net~meredithlamb/zero- torque-suspension.html
of a study by Meredith Lamb on zero-torque-suspensions)

zero- torque-suspensions

A crude tabletop edge experiment of a "zero torque suspension" wire hinge/flexure ("Figure of Eight), on a hanging pendulum for a horizontal sensing seismometer Oct 17 2005 bv Meredith Lamb

Credit goes to Chris Chapman in the UK, as he suggested this suspension for a trial to suspend a hanging pendulum.

Simply put; it uses two wire loops which suspend the pendulum and they are simply twisted about to support a structure (the S-G type, "Tee" frame) below. Chris suggested music wire (mandolin) that is .008"/0.2mm in diameter, (~3 foot long) which was obtained from a local musical instrument shop for ~$1.40. The prices in various places will likely range all over the place. In the picture below, the initial two wire loops ends are simply wrapped around one screw and held in position with nuts on the upper rod, which uses setscrew couplers. The upper rod/coupler is locked in position and does not move. The bottom bar and couplers for some of the experiments, does not clamp on the wire, but will likely have to have such in a real operating seismometer. Make sure the wires do not touch where they "cross over". It "looks" rather strange, but it works excellently. There is not really a "zero" torque, as the wire/rollers will always offer some dampening or friction, but, it's so much better than just a simple hanging suspension that the name would seem appropriate. For those who don't know; a S-G (Shackleford-Gunderson, hanging pendulum) is used as horizontal seismometers, or two instruments pointed in opposite directions would be needed for a normal multi-component directional sensing seismographic stations setup.

Be aware that only the 0.008" diameter size of music wire was tried here. Other sizes like 0.006" or 0.010" could give similar or perhaps even better results. There are other types of wire; that are of a small diameter and might have a similar tensile strength to make them useful, but they are unknown/untested.

The original inventor of this "general type" of hinge/flexure was Donald Wilkes (now deceased) of the UK; who used flat metal strips (foil/tape/spring) on rollers...sometime around 1968. It was subsequently called a "Rolamite" (commercial name) hinge/flexure, and later (when?) wires were also tried. However, for this specific hinge where there are two looped and twisted wires, it's a real mystery as to who the true originator of such was. This particular "roller" hinge/flexure/suspension, has not been personally noted to have ever been used in hanging pendulum amateur seismometers that I am aware of, although it has been used in a amateur horizontal and verticals with high success according to a email search of PSN. This suspension for a hanging pendulum seems a lot more sensitive to movement than any previous "S-G" suspension that I know of...which is solely the use described here. The "zero-torque-suspension" aspect does come solely from using spring like wire that flexes and rebounds; using a non "springy" material likely won't achieve nearly the same result.

The first positive aspect for this suspension is its amazingly very long induced oscillation (or harmonic motion) decay. The ~1.75 pound SG model frame/boom/mass below was offset 2"and allowed to oscillate freely with no dampening system thereon. The pendulum oscillated for slightly over 10 hours! In comparison, the best of several trial suspensions I recently tried for a S-G, that used a few sizes of ball bearings on samples of glass/optic surfaces, or various metal/carbide surfaces, could not oscillate much beyond a maximum of from 4 to 6.1 hours. Ball bearings can be used for other hinge areas on other types of seismometers with excellent results. For a view of the general model SG test model used, and related trials with ball bearings on various surfaces, see:

http://home.earthlink.net/~meredithlamb/ballbearinghinge.html

The second positive aspect for this suspension is that while other ball bearing suspension methods would die off VERY rapidly where the initial mass offset is small (on the order of 1/16"/1.57mm), but this model's oscillation would continue for 3-4 hours thereafter! In other words, with small seismometer frame/earth displacements (seismic disturbances), this pendulum's suspension is such that these very small movements would seem to be much easier to discern with the (capacitive or light) sensor used. Chris wrote that there is a capacitive sensor that does not need the central moving electrode to be electrically charged, and is called a "Symmetric Differential Capacitive (SDC) sensor. The following URL forwarded by Chris is a very good tutorial:

http://phvsics.mercer.edu/petepag/tutorial.html

I have used a homebuilt "S-G" (Hall sensor) which used a couple of strips of 0.002" thick by 0.25" wide by ~1" long brass, for a suspension/hinge (Cardian) in the past. Its free oscillation maximum was about 35 minutes. With this "replacement" suspension, the free oscillation in the same S-G frame could potentially be slightly over 17 times longer. There is one main feature of a S-G that could be "highlighted", is that its ground tilt drift is a lot less than a "hanging gate" type horizontal seismometer. One negative of a S-G, is that the sensor would have to have a lot of amplification or its sensors would have to be capable of such. One suggested sensor for this specific electrically uninsulated setup would likely be the differential light and photodiode circuit, near the mass that was created by Chris Chapman some time back. See the "Differential Photo Detector" circuit (PhotoDet2.gif, or, PhotoDet2.pdf) on John Lahr's website at:
http://jclahr.com/science/psn/chapman/photo detect/index.html

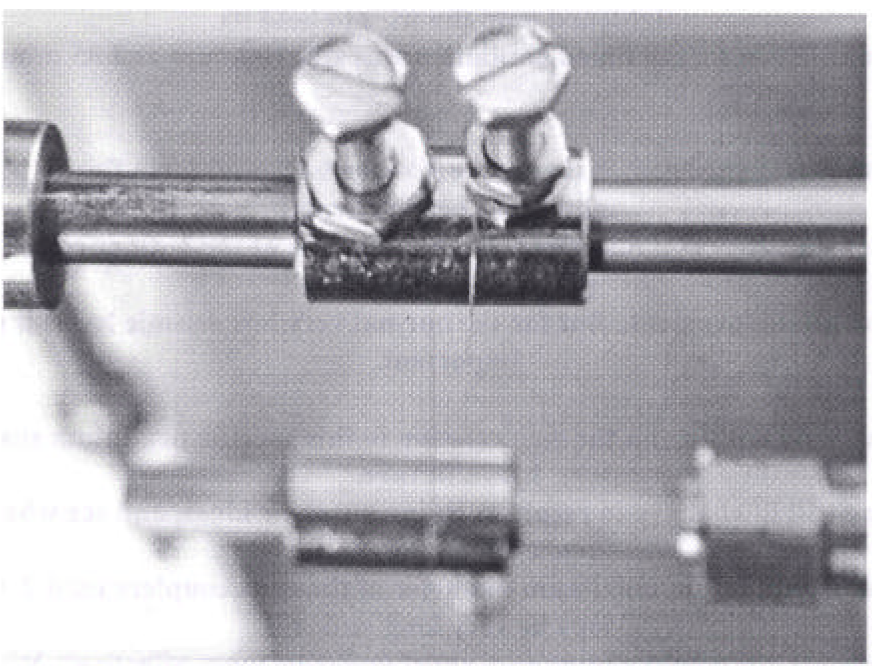
Its also quite possible to electrically isolate the upper support assembly to accommodate another sensor. One could also try running fine coiled "signal" wires somewhere off the support frame or rod, down to the S-G boom/Tee, and further down to the sensor used, but it would be delicate to do (which is normal).

According to Chris, the center of oscillation of this setup is atop the top rod. This means that the length from the top of top rod/coupler and the ~ center of the mass determines the natural period of this pendulum. It also means that having long wire loops isn't such a detriment as one would normally believe. While I used what I consider as long loops here, there is probably a limit to how long the loop/s could be, as opposed to being practical.

[missing photo in printout: zerotorquesuspensionl 001]

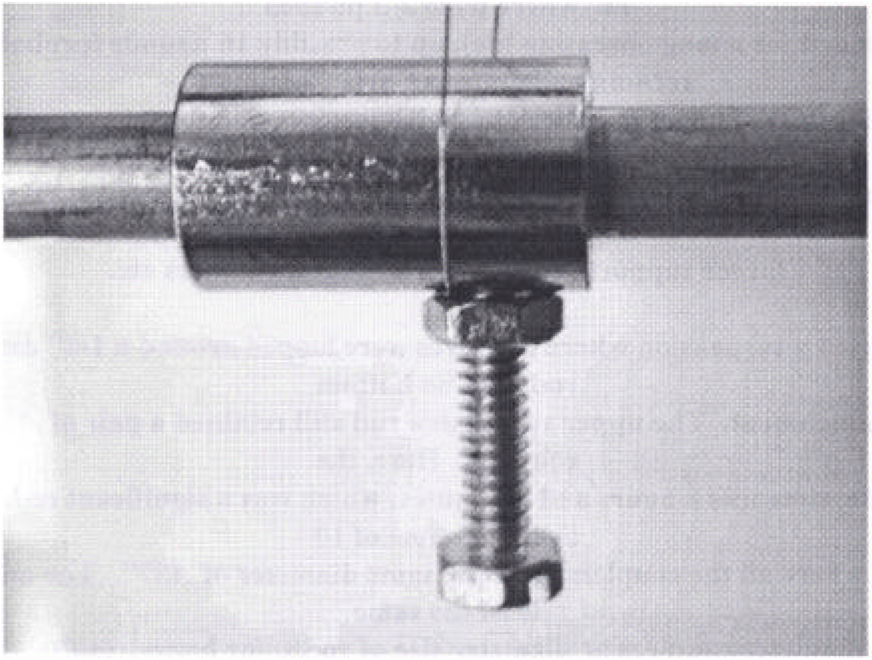
The picture below is a view of one the top rods shaft couplers for this trial suspension. Here, the screw is tightened down to hold its position on the horizontal rod. In the foreground the first end of the wire is wrapped around the screw and a nut is tightened to hold that end from moving. The other end of the wire is wire wrapped around the screw above the bottom nut, and another nut is used to hold that end of the wire loop in place. Crude; but it was just a initial first test connection. The rod used is 1/4" in diameter, and the double setscrew shaft coupler is .437" in diameter. This type of connection is only good for a test, but the wire ends will be likely unusable later as the bending ruins that part of the wires, as they are very subject to breakage from any straightening afterward. The "Tee" and boom/mass support is a U.S. common 1/4" three inlet/outlet pipe compression item...quite handy for this test model and it was also suggested for use by Chris Chapman some time back.

[missing photo in printout: zerotorquesuspensionl 003]



zts-4 terminaltest001

The above photo is another trial of where the two ends of the wire loop are held in position by two screws/nuts on the coupler shaft. Surprisingly, the free oscillation time didn't change. It swung for 10 hours and 50 minutes. Here, the bottom rod shaft coupler does NOT anchor/clamp onto the wire -- it is only going around the coupler. Again; the ends of the wire will be bent too much, and will likely have *to* be cut off *to* salvage the rest of the wire.



zts-4 terminaltest003

The above photo is of the left side bottom rod/shaft coupler, where the nut is lightly finger tightened onto the wire to hold its position. Even so, the timed oscillation was still 10 hours and 35 minutes.

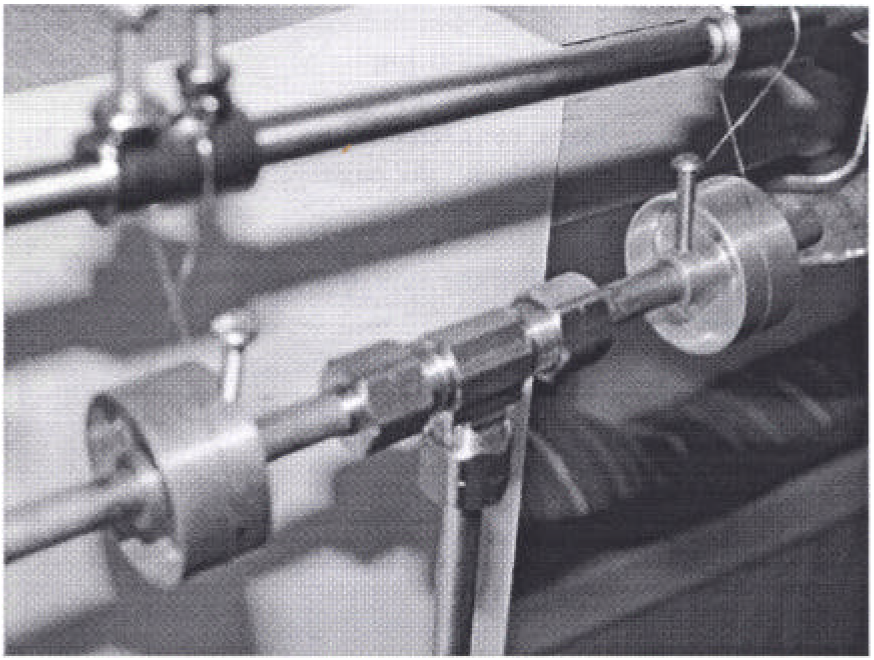
One negative with this suspension, is that while it rocks back and forth fine, it is also subject to movement perpendicular to the desired sensing direction (out away along the length of the bottom rod sides). There is probably some way to help limit that potential movement...but for the normal very low seismic levels it may not be that important.

There seems to be nothing on the web relating to this specific pendulum suspension or hinge/flexure. Being as such; one will likely have to resort to trying out their ideas, and see whether the results are adequate. For example, is there a minimum/maximum diameter of the rods/couplers used? Can the wire loops be very long and still work effectively (?), or, would a minimum short loop/s be more effective? Would smaller diameter wires change the results significantly? There are likely many more questions related to this suspension which entice one to try, and find out!

Mechanically, there are a variety of ways of connecting the wire to the upper rod. The music wire used is such that it doesn't like very sharp immediate bends like 180 degrees, (no music wire does) as it weakens the wire and can snap/break apart. Other than that, the tensile strength is such that the wires can support anywhere from 2-3 pounds (recommended for a long operating life), up to possibly 16 pounds (probably NOT recommended per Chris Chapman tensile strength figures) of boom/mass weight which is very good for mass inertia; or the mass remaining in place, while the earth moves underneath. If one wants more boom/mass weight, I'd suggest larger diameter wire and stronger, larger support rods and screws/shaft couplers etc.

Oct 13 2005: I tried a suspension where the wires were looped around a 1/4" diameter bottom rod with no bottom wire anchor attachment. The upper suspension rod still retained a pair of 0.437" diameter couplers. Here, the total oscillation time was 8 hours and 5 minutes; which was a significant reduction of the averaged time of 10 and 1/2 hours where all the couplers were the same diameter of .437". The message; use at least the same diameter couplers or diameter size of rod/s, for better results. *(This is very likely due to higher stress on a smaller diameter roll leading to more bending loss –crpatton)*

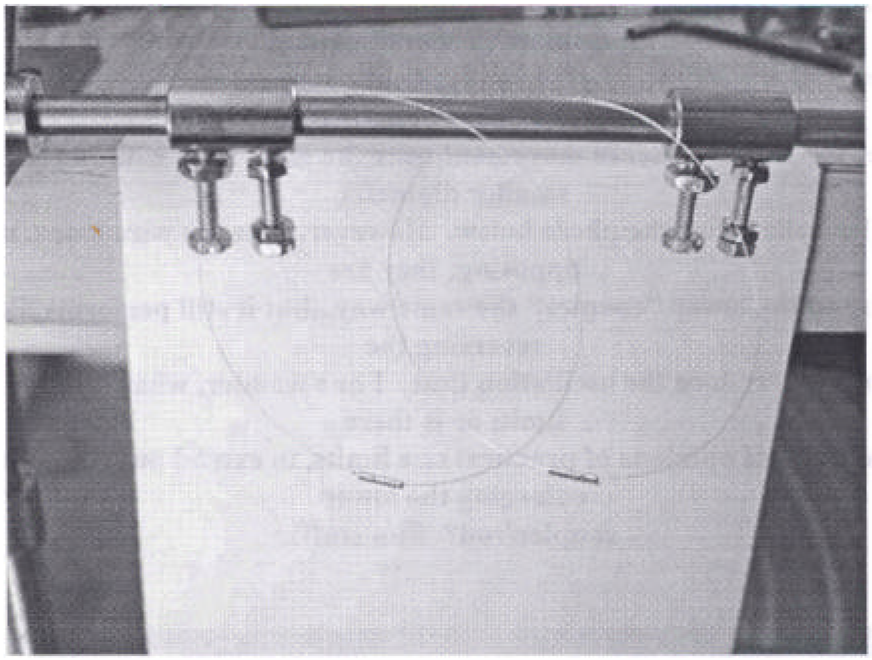
Oct 15 2005: Next, I tried a suspension (below) where the lower wires were looped around a pair of 1.015" couplers on the lower rod. The upper suspension rod still retained a pair of .437" diameter couplers. Now this arrangement yielded a most interesting extension of the total oscillation time out to ~12 hours! The aluminum "rollers" used or adopted (drilled and tapped) were off a conveyor like surplus assembly. Noteably; the last couple of hours of oscillations was much easier to visually observe movement near the mass than with the tests involving a smaller diameter lower rod/coupler/roller. See the photo below. However, note the wire loops, which are not opposing; they are both wrapped around the lower "coupler" the same way...but it still performs like a ZTS. Yes -- reversing the couplers positions will reduce the oscillation time. I wonder, what's the real physics size limit; or is there any; other than individual opinions of practical size limits, to extend out the oscillation time via enlarging the lower coupler/rod? Fun stuff!



ztslowerbarlarger004.j pg

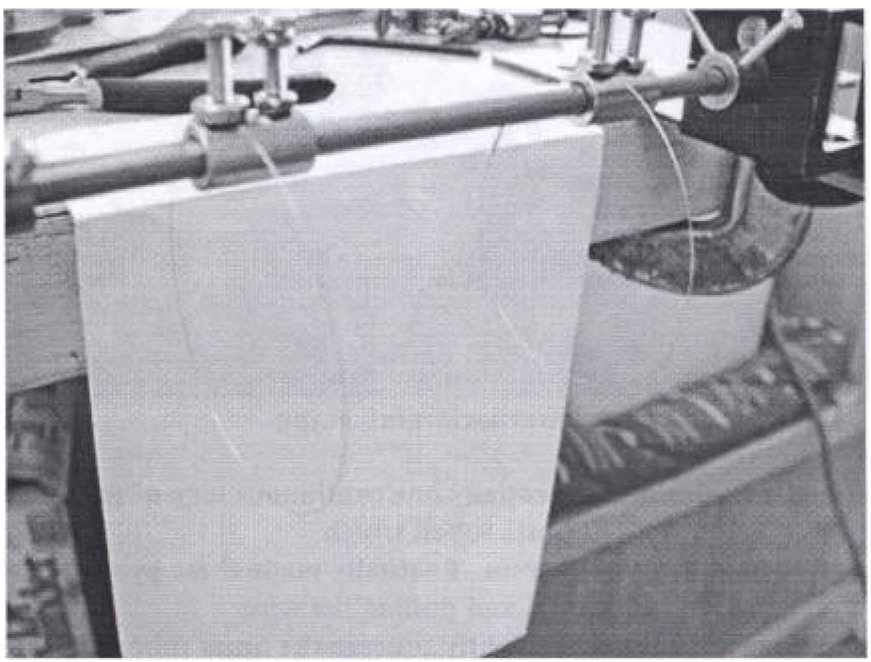
The below photo is of a trial, where essentially one continuous loop of wire is joined by small brass tubes, which were compressed to hold the wire therein. I actually made these by using a full pop can diameter, and pulling the wire snug and using a pair of wire cutters to lightly squeeze the brass tube onto the wires inside.

Then I compressed the joint in a vise. The OD/ID of the wires varied a bit, but they were good enough for further trials. With a smaller diameter wrapping loop forming tube/pipe, the OD/ID/length will change. This rough method leaves a lot to be desired for forming a couple loops that are of the same dimensions/hanging lengths.



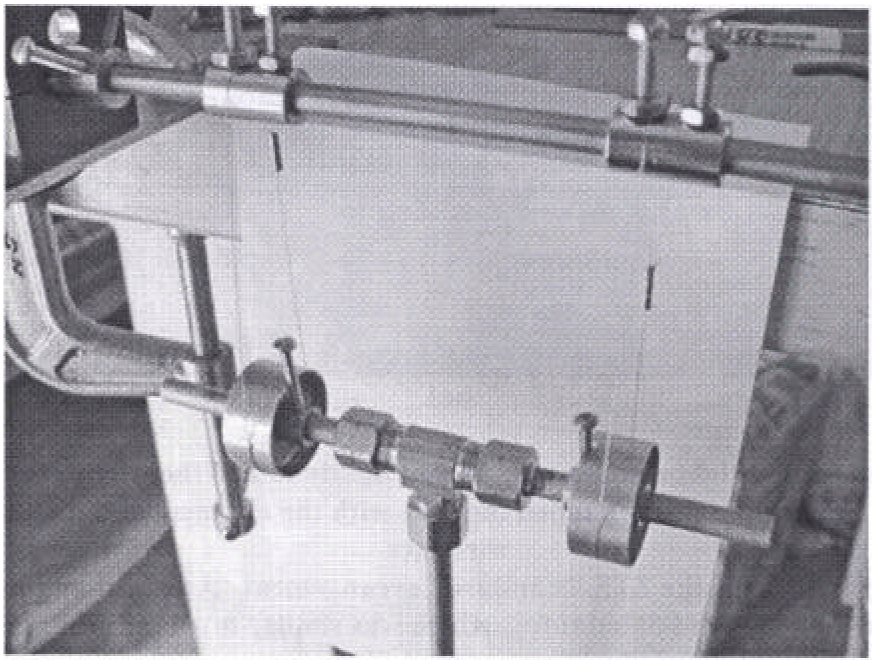
cwe001.jpg

The below photo is of the two wire loops, connected to the top rod/couplers, by only using one nut to "lock" the position.



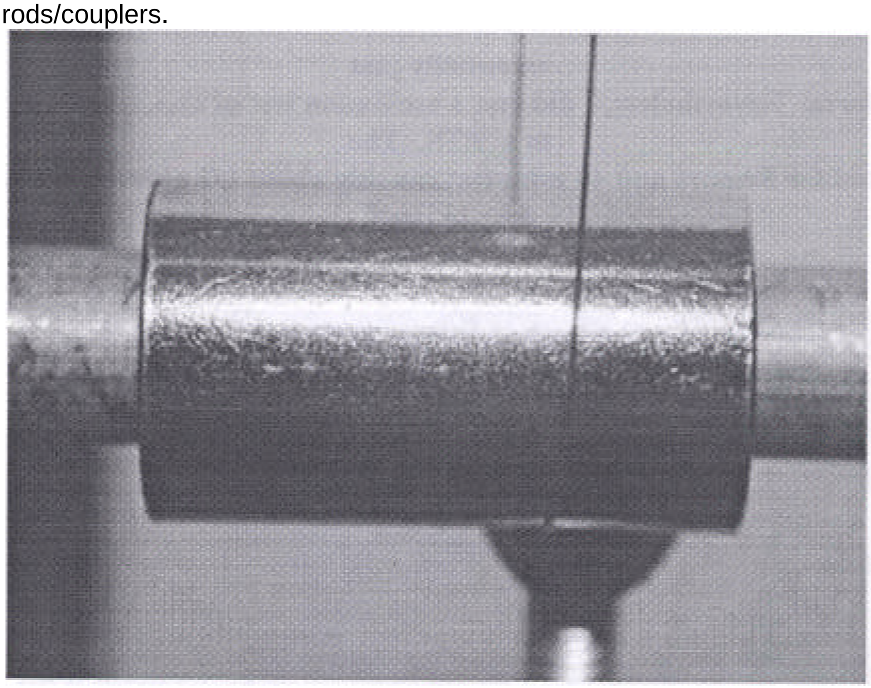
cwe002.jpg

The below photo is of the wire loops just wrapped around the bottom bar/couplers. The setup is essentially just a "S-G" in this form. Nevertheless, I did run an oscillation test of this, mainly as a comparison to a ZTS. The assembly oscillated for 5 hours and 40 minutes; roughly about 1/2 as long as a ZTS, not a bad time in itself.



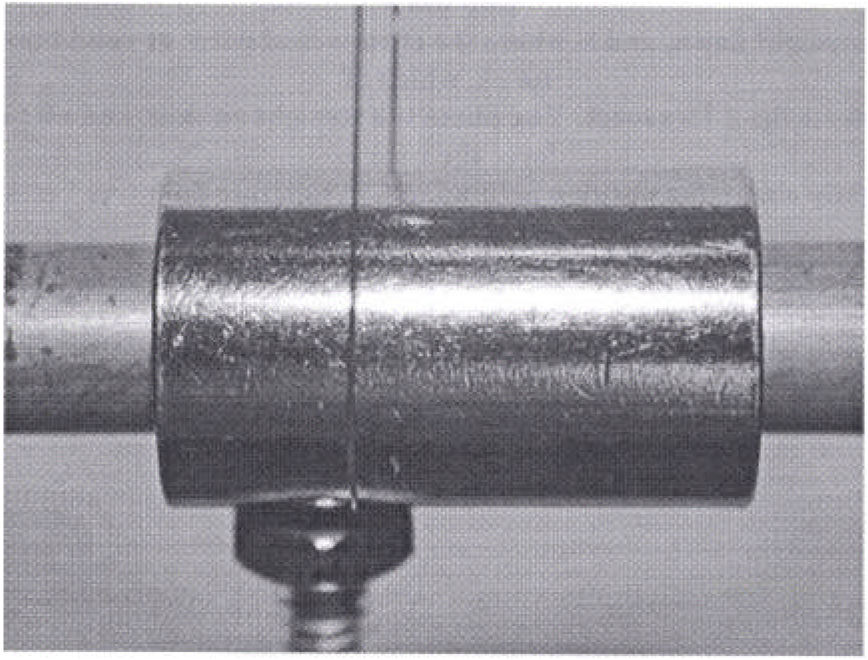
cwe003.jpg

The photo below is of the left bottom 0.437" diameter coupler/rod. With this wire loop as is; the loop has a tendency to hang straight down, and is where the crossover of wires are and they can potentially touch, which of course would defeat the ZTS aspect. The photo is a straight on shot, and all I did was lightly force the wire to the left and lightly clamp the position holding nut, to separate the wires" cross over" area between the rods/couplers.



be1.jpg

The photo below is of the right coupler rod. Here I lightly forced the wire to the left up against the screw/bolt, and again lightly clamped the wire with the nut against the coupler. Note the wires are looped opposing; and this is the ZTS "standard" arrangement. As is, with a time trial test, the oscillations lasted 10 hours and 55 minutes...which was similar to all the other previous types of hookup suspensions.



bc2.jpg

If you are following the above wire arrangement for a standard ZTS, naturally their arises the question of what would happen when both wires loops are set up the same way. A time trials oscillation test was run once again, and the total oscillation time for this same loop wiring setup was 10 hours and 37 minutes, not much difference between the two, but based on this long oscillation result, apparently using either wire way, it’s still a "ZTS".

Besides regular shaft couplers with two setscrews, one could likely use some of these "old time" phosphor bronze bearings where the ID of the bearing matches the OD of the rod they wish to use; and drill/tap those. If you have the size of drill and tap to do so, one can buy such cheaper than a coupler with the set screw holes already machined into them. They are getting real scarce in hardware stores nowadays, but they are still available on the web. Chris also mentions that having very smooth rods/couplers would extend the oscillations times, which I'm sure such would, but I think it isn't really necessary here as the results were already so very good.

Chris Chapman suggested this approach to equalizing the length of the loops, where the two top shaft couplers are machined to pinch the wires. First it involves enlarging the ID (inner diameter) of the couplers by an amount that will allow two wires to enter under the next operations "bridge", by roughly 0.008"; the same diameter as the wire used. Next the couplers are sawed part way in the middle section of the coupler to where it creates a metal "bridge" spanning the two sides of the coupler. The couplers are mounted on the top rod, and one should create two "X" length spacers" to run in between the top and bottom rods, and side clamp the assembly to hold the rods and spacers in a fixed position. Now the wire is wrapped around the bottom rod, crossed, and each wire end is run/threaded under the coupler’s new "bridges", and pulled snug. The couplers two screws are tightened, and with care, the wire loops should be of equal diameters/lengths.

Chris Chapman suggests another possible better method of equalizing the length of the loops. This involves drilling a hole in either one or two bolts on the top coupler/rod and tightening down with a nut. One would have to make certain that the hole in the bolt faces the incoming wire/so One would have to mark the position on the tread of the bolt/screw, file, and then drill the hole. Of course, a brass bolt/screw would be the easiest to work with. Using the two drilled bolts/screws per loop might be easiest, where, one bolt/nut, just holds one end of the loop and the other end of the wire does through the other drilled bolt and is adjusted for whatever length adjustments are necessary. One aspect of this, is that with the two bolts being separated, it automatically creates a lateral placement of the wire loop where when connected to the lower rod/coupler, there shouldn't be any wire touching the other in the area where they cross. Here, in addition, its possible to introduce a object that is placed between the upper and lower rod/couplers to get the more exact distance desired to equalize the loops length to the lower rod/couplers.

Yes, the setups above are rather large, but I'm sure most sizes can be reduced, and their is probably a infinite number of ways and means to make the mechanical upper rod secure, and likely just as many ways to form the "T" boom shape, other than the pipe "Tee" shown. One can also just drill holes and tap a screw/bolt in the rods used, rather than using setscrew shaft couplers. However, I think at this time that a 1/4" diameter rod might be rather too small (too sharp a curve) for the suspension wires, but I could be wrong. Actually, I was wrong on a lot of "guesses" on this suspension, that were made prior to any timed oscillation trials.

The main" supposition" I'm making here for this type of suspension, is that because it has a zero torque suspension, and of course it can oscillate a very long time, due to very low dampening/friction, it would be much/more sensitive to ground motion than any other type of suspension for a hanging pendulum that I know of.

Chris Chapman has denoted that this suspension would likely be very good for a pendulum grandfather clock.

I'd think such might run on a lot longer than most present day spring "powered" pendulum clocks; but I don't know how they exactly operate myself. Many thanks to Chris Chapman for many email consultations and suggestions during the course of this trial!